

## Avian Flight

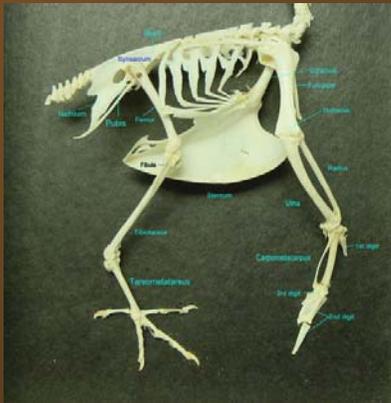
- |                         |                      |
|-------------------------|----------------------|
| I. Anatomical Structure | III. Types of flight |
| A. Avian Skeleton       | A. Gliding           |
| B. Flight Muscles       | B. Flapping          |
| II. Aerodynamics        | C. Soaring           |
| A. Lift                 | D. Flight control    |
| B. Drag                 |                      |
| C. Thrust and Power     |                      |
| D. Wing Types           |                      |

## A. Avian Skeleton

Uniquely structured for flight

- fusions
- reinforcements

Make skeleton powerful and lightweight



### 1. Pneumatic bones



Cross Section of a Bird Bone: Light, Hollow, and Strong



- large, soaring birds (e.g., albatrosses, vultures, & hawks) have pneumatic bones
- divers (e.g., loons) must be 'heavier' to dive & so do not have pneumatic bones
- small birds (e.g., many passerines) do not have pneumatic bones

WHY???

2. Keeled sternum

Sternum has large keel – carina, serves as anchor for major flight muscles

Flight ability correlated with size  
(exception – Penguins!)

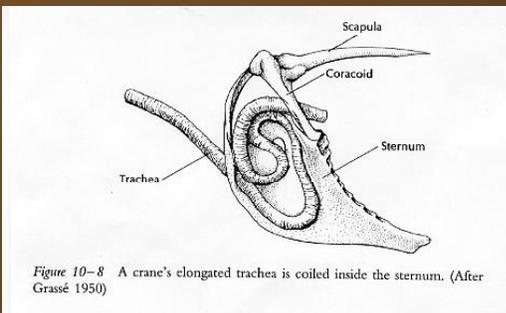
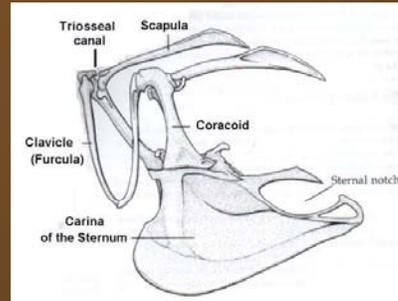


Figure 10-8 A crane's elongated trachea is coiled inside the sternum. (After Grassé 1950)

Skeleton designed to withstand strains of flight

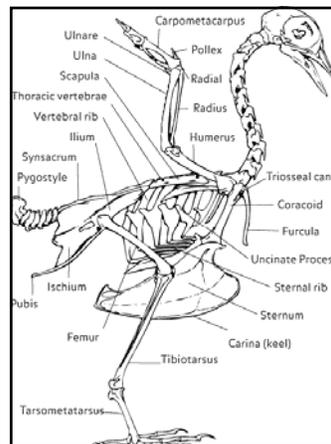
3. Thorax rigid and reinforced

- a. ossified dorsal and ventral ribs (strong connection between breast bone and back bone)

b. tightly articulated vertebrae



notarium



- c. ribs with upper (vertebral) & lower (sternal) segments that connect the vertebral column with the sternum

d. uncinat processes overlap successive ribs to reinforce rib-cage

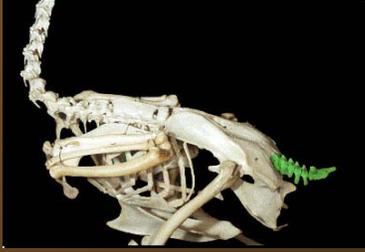


4. pelvic region:

a. pelvic (innominate) bones are fused with lumbar & sacral vertebrae. The fused portion of the vertebral column is called the **synsacrum** & it's composed of the last thoracic vertebra, the lumbar, sacrals, & anterior caudals.

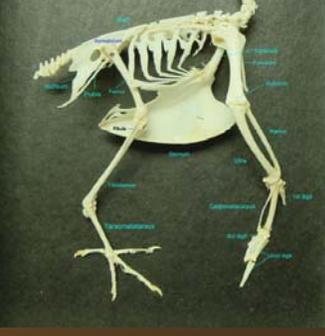


b. last few caudal vertebrae are partially fused to form the **pygostyle** (that helps support the tail feathers)

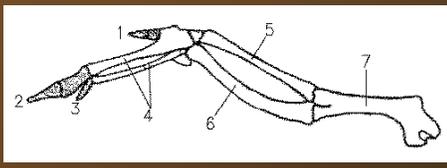


5. Forelimbs

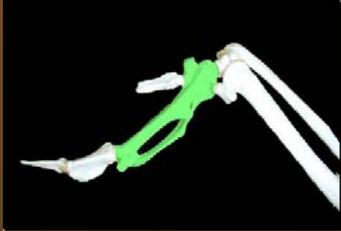
a. ulna – enlarged (bone that supports secondaries)



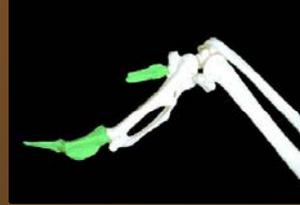
b. carpal bones (wrist bones) are reduced in number (just 2)



c. metacarpals (palm bones) - 1st & 5th metacarpals are lost; 2nd, 3rd, & 4th are united (with vestigial carpals) to form the **carpometacarpus**



d. digits - only 3 (rather than the typical 5 found in most vertebrates)



6. hindlimbs

a. proximal tarsals are fused with the tibia to form the tibiotarsus



b. distal tarsals are fused with metatarsals to form the tarsometatarsus



## B. Muscles

1. reduction in some muscles to minimize weight:

a. jaw muscles are reduced in many birds (powerful muscles often unnecessary because food is swallowed whole or in large pieces, e.g., owls)

b. hindlimb muscles reduced in many species because: the rigid skeleton of birds (hindlimb, pelvic girdle, & synsacrum) provides much support &, as a result, less musculature is needed

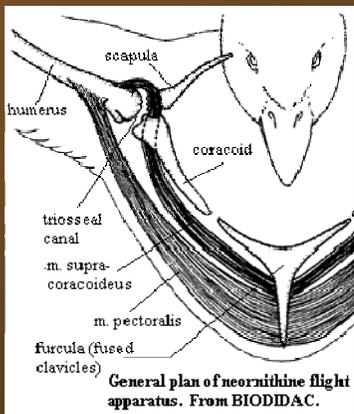
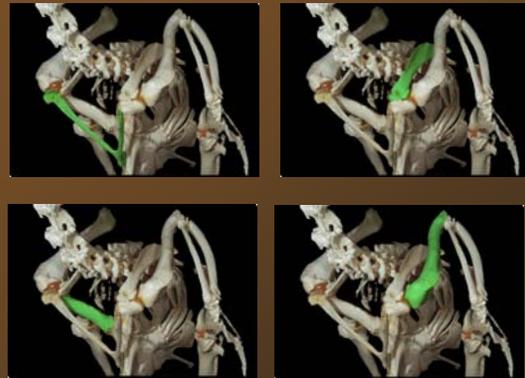
hindlimbs are sometimes used for little else but perching (e.g., hummingbirds & swifts)



2. Flight muscles (pectoralis & supracoracoideus) are very large & located near the center of gravity:

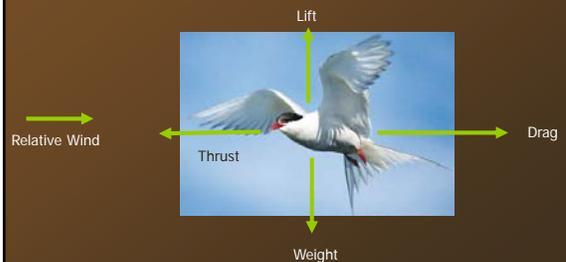
a. pectoralis or downstroke muscle - originates on the keel and inserts on the underside of the humerus

b. supracoracoideus or upstroke muscle - originates on the keel and inserts on the upper side of the humerus



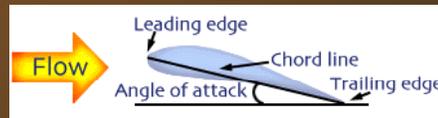
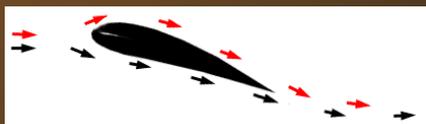
II. Aerodynamics

4 forces balanced to maintain level flight at constant speed



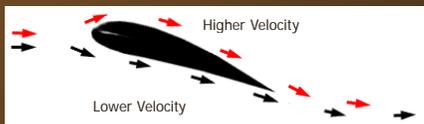
A. Lift – force produced by flow of air over airfoil

Airfoil – asymmetrically curved structure, tapers toward posterior



Avian wing (primaries) function as airfoils

Flow of air generates differential velocity above and below airfoil



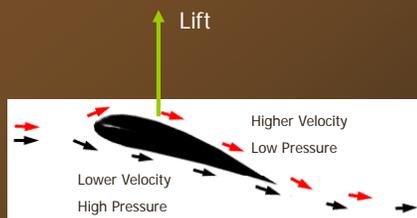
Bernoulli's Principle –

Greater the velocity of a fluid the less pressure it exerts

Pressure of a gas is inversely proportional to its velocity –

High Velocity = lower pressure

Low Velocity = higher pressure



Lift can be increased by several factors

1. Increasing airflow (speed)

Lift increases by square of velocity



2. Changing the angle of attack

Increase angle increases lift (to some extent)



Too much – interruption of laminar flow resulting in stall



Blockage of downward flow of air over upper surface causes a loss of lift = stall



## Avian Flight

### I. Anatomical Structure

- A. Avian Skeleton
- B. Flight Muscles

### II. Aerodynamics

- A. Lift
- B. Drag
- C. Thrust and Power
- D. Wing Types

### III. Types of flight

- A. Gliding
- B. Flapping
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Reduced camber – reduced pressure differential – reduced lift.

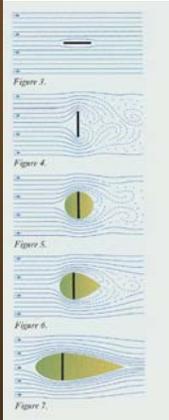


3. Change the camber of wing  
 Camber = shape of the anterior portion of airfoil



Increased camber - increased pressure differential - increased lift.

B. Drag  
 Moving air has different properties from stagnant air.  
 Air resists motion - drag.



Frictionless flow over airfoil not possible  
 Any slight turbulence reduces lift.

2 types of drag

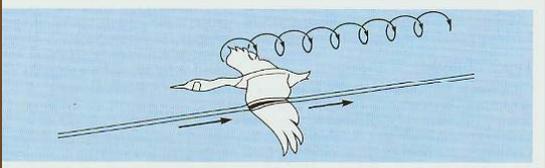
1. Induced drag
2. Profile drag

1. Induced drag  
 Leakage of air around wingtips reduces effective wing area for lift production.

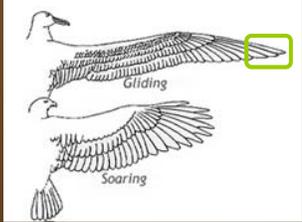


Figure 17. Air "leaking" from underneath a wing to the top surface.

Air moves around tip and pressure equalizes, reduces lift.



Shape of wings can affect induced drag.  
 Pointed wings generate less induced drag than rounded wings

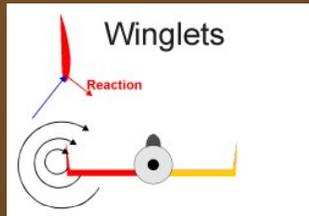


Small area creates less turbulence

Induced drag also decreases with increased airspeed.

Flying in formation can overcome induced drag.

Cancels some of air turbulence at own wingtip



Another solution is to increase aspect ratio of wing

Aspect ratio = length / width (1.8 – 18)

Large aspect ratios become more difficult to maneuver.



Compare aspect ratios of hawks



Birds also reduce induced drag by emargination of primaries.

Generate series of smaller airfoils, increasing lift.



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### 2. Profile drag

Friction between air and birds body and wing surfaces.

Thin leading edges minimize.

Profile drag and flight power required to overcome it (profile power) increases with airspeed.

Harder to throw Frisbee into strong wind than light wind

Long narrow wings reduce profile drag – best for fast flying birds.



3. Problem – How to maintain lift at slow speeds?

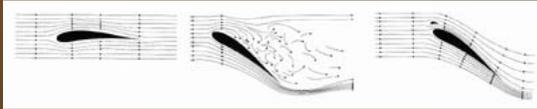
a. Increasing angle of attack can increase lift at slow speeds.

Increasing angle can result in stall – stalling angle of attack.



b. Auxiliary Airfoil

Stalling angle of attack can still provide lift if auxiliary airfoil placed in front or behind wing.



Called slotting the wing



Slots also can be placed behind wing



Two types of slots  
Slots to prevent stalling  
Slots to increase lift

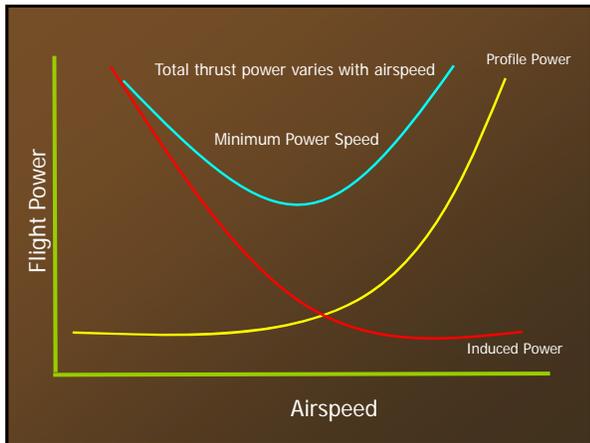
As air forced through slot – expands on upper side reducing pressure and increasing lift.



C. Thrust

Power to overcome drag.  
Downbeat of wing provides thrust

$$\text{Total thrust} = \text{Induced Power} + \text{Profile Power}$$



Minimum power speed – speed at which bird uses fuel more slowly

Most fly at 30 – 60 km/hr

Relationship exists between amount of time spent “on the wing” and energy expended during flight



30 min/day  
20x energy



18 hrs/day  
3x energy

D. Wing Types

Lift & Drag forces vary with size and shape of wings

- Aerial/open country birds – long pointed wings
- Dense forest – short, rounded wings

Define wing size and shape

1. Aspect ratio (see above)
2. Camber (see above)
3. Wing loading

relationship between wing area and body mass of bird

Mass (g) / Wing Area (sq cm)

House Wren	.23
Black-capped Chickadee	.16
Red-winged Blackbird	.29
European Starling	.44
Common Loon	1.8

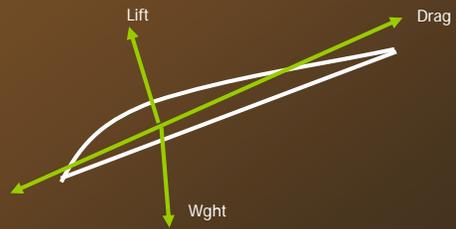
### III. Types of Flight

3 basic types

- A. Gliding
- B. Flapping
- C. Soaring

#### A. Gliding

Requires no propelling energy from bird.



Problem – end up below where started, no propulsion

- pull of gravity
- resistance of air to passage



Most proficient gliders → 15 – 20 m while descending only 1m



#### B. Flapping flight

Adds thrust to overcome effects of drag.



Difficult and not completely understood

Beating wing flexible

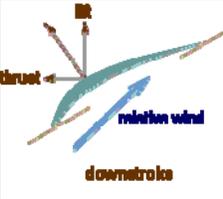
- shape
- expanse
- aspect ratio
- camber
- position of feathers
- varies between species

Wings acting as both airfoils and propellers

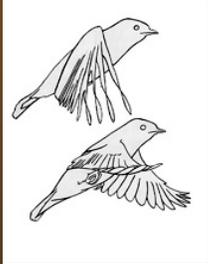
- the proximal part of the wing moves less & provides most of the lift
- the distal part of the wing moves through a wide arc and generates most of the thrust that propels a bird forward.

Each primary functions as individual airfoil.

During downstroke primaries change orientation downward from horizontal, portion of upward lift changes to forward thrust



During recovery or upstroke primaries move together reducing resistance.



Upstroke largely passive – some birds (rock doves) do get thrust

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C. Soaring flight

Complex – combines both flapping and gliding

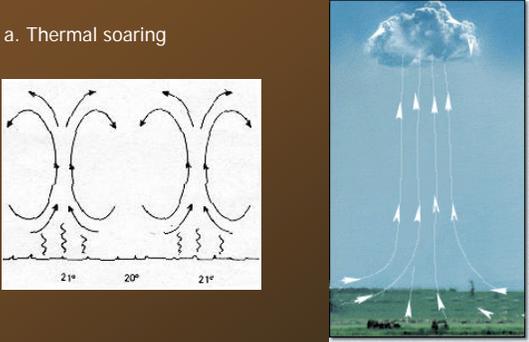
Birds use upward currents and glide down through columns.

2 types

1. Static soaring
2. Dynamic soaring

1. Static soaring – birds utilize updrafts of air

a. Thermal soaring



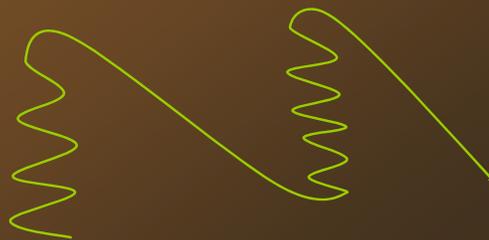
Birds associate with column of air, remain aloft with little effort

Thermals narrow – need low aspect wing to stay within column



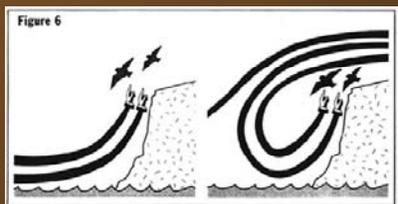
Migration accomplished using thermals.

Occur over water where air temp colder than water (North Atlantic)



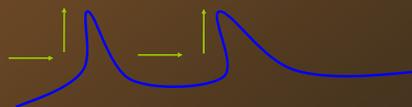
b. Slope soaring

Many spp migrate down coastlines using this type



Shearwaters, petrels can even use trough of wave.

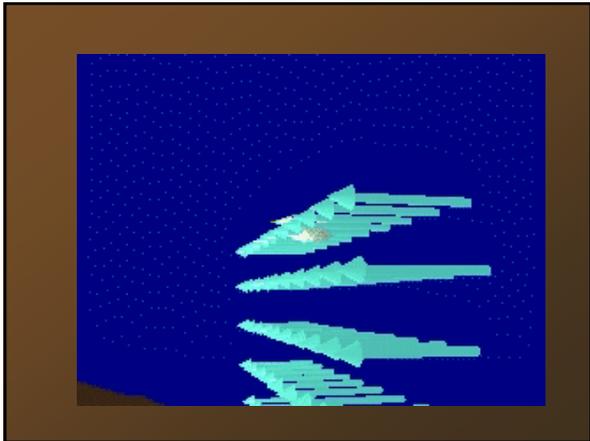
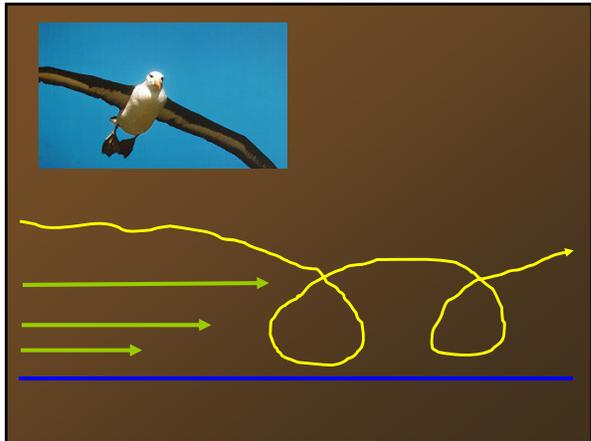
Rising air currents formed on windward side of waves



Prevailing westerlies create migration routes for birds.



2. Dynamic soaring  
Oceans – thermals unreliable, wave-deflected updrafts too small & too near surface for most birds  
  
Over wide stretches another energy source exists  
  
Steady winds (trade winds)  
Friction with waves causes wind speed gradient.



Requirements

- heavy body
- low wing loading
- low drag
- high aspect ratio (Wandering Albatross 18:1)

D. Flight Control  
3 axes  
  
Of evil  
Iraq  
Iran  
North Korea

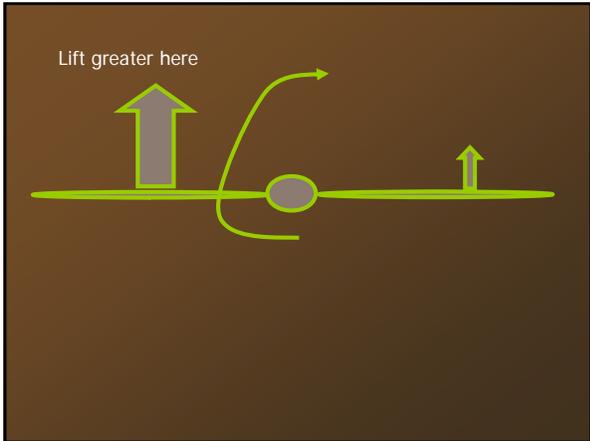
D. Flight Control  
3 axes of flight control  
Roll  
Pitch  
Yaw

1. Pitch – controlled by combination of movements  
Depressing tail – bird moves up  
Raise tail – bird goes down  
  
Pectoral girdle  
Move wings forward – bird goes up  
Move wings back – bird goes down

2. Control of Roll  
Control lift on each wing separately  
Altering erection of wing coverts



12,000 separate cutaneous muscles in wing of goose.



3. Yaw  
To turn a bird must initiate a roll  
Tail can also be used



- During the downstroke (power stroke), wing moves downward & forward.
- Trailing edge of the wing bends upward (due to the air pressure) and this transforms the wing into a 'propellor' & moves the bird forward.